is a portion (*AZB* in fig. 5) of the sky image upon the negative which duplicates the first part of the picture. In order to obtain a correct picture of the sky the duplicating segment of the negative film is cut away and the edges are brought together. (In fig. 5 the segment *BZC* was cut away and *ZB* matched against *ZC*.) The final photograph, as shown in figure 6, is then made by means of transmitted light through the conical negative, which represents the dome of the sky. The sensitized circular film may be replaced by a conical film, with a slight modification in the construction of the camera. By the use of the conical film the size of the camera may be reduced, while the operation of cutting away the overlapping segment of the circular photograph is eliminated.[1]

Advantages of the new camera.

What advantages are offered by the use of the new form of camera, over the forms now in use, especially in the field of cloud photography? In the first place the new device can be utilized for all purposes now served by existing forms, and in addition yields results not to be obtained by means of the latter.

Our ignorance concerning cloud forms and their significance is still rather more conspicuous than our knowledge. It is reasonable to assume that a more accurate survey of cloud forms over an extended area and the rapid changes which they undergo will lead us to a better understanding of the nature and movements of storms and weather changes. A cloud is a visible process rather than a finished product, and is in many instances the only evidence we have of the forces at work in the upper atmosphere. A photograph which embraces the entire field of view opened up before the observer, and depicts all of the cloud forms—their relative positions and their extent—is manifestly of greater value than a photograph which shows only a small detached cloud, or portion of a cloud, and which gives no evidence of relationship with the general condition of the sky.

The problems of cloudiness may be profitably studied by means of a detailed study of individual cloud forms, just as it is a common and profitable practice to study forestry by the study of individual trees; there are, however, problems of clouds in association with other clouds, which can not be successfully solved in this manner, just as there are problems of trees in association with other trees, or the larger problems of forestry, which the study of individual trees will never suggest. The new form of camera will make such general cloud studies possible and profitable.

One of the simplest and most obvious uses of the new camera is to obtain a permanent and true record of the amount and character of the cloud cover at stated intervals during the day. The only method now in use to obtain this end is by means of eye observations, which are liable to errors of judgment, and at best are only rough estimates of the proportions of the sky covered by the principal cloud forms.

Photographs of the sky at stated intervals, taken simultaneously at a number of stations within cyclonic and anticyclonic areas, would afford valuable material for the advancement of our knowledge of storms. Assuming that one of these photographs will show the amount and character of the cloud cover over the area of from 200 to 300 square miles, a comparatively few stations equipped with the new camera would furnish detailed information as to practically every kind and phase of cloud form within the area of a well-developed cyclone or anticyclone.

The design of the new instrument seems to be entirely satisfactory, and the cloud photograph here reproduced in figures 5 and 6 was made by Mr. Mueller by means of the temporary wooden camera, constructed entirely by himself and shown in figures 1–4. It is very desirable, however, to provide for the construction of a more permanent instrument, in order to facilitate further experimentation in the technique of cloud photography, and to demonstrate the value of the camera as an instrument for systematic research, and for daily use at meteorological observatories.

[1] Mr. Mueller is now constructing such a modified model with a conical film in accord with these suggestions—O. L. Fassig.

A TEST FOR PERSONAL ERROR IN METEOROLOGICAL OBSERVATIONS.

By ERIC R. MILLER, Local Forecaster.

[Dated: Weather Bureau, Madison, Wis., Mar. 23, 1915.]

The object of this paper is to call attention to the value of the daily rainfall-frequency distribution as internal evidence as to the reliability of climatic data. Internal evidence is often the sole dependence of the climatologist in weighing raw data, since the observers are necessarily isolated, and hence are not subject to personal inspection and supervision. The degree of neatness of the observer's reports affords only indirect evidence of the fidelity with which the observations have been made, especially as the majority of volunteer observers—the principal source of climatic data—are likely to be above the average in general education, although they may have had no training whatever in scientific accuracy. Even this indirect evidence is not available to many who have only the neatly printed tables of data presented to their inspection.

Rainfall-frequency distribution is determined by classifying the recorded daily rainfalls according to magnitude, one class for each unit of the scale used in measuring rainfall. In the United States rainfalls are recorded to hundredths of inches, hence such a table shows the number of daily rainfalls of "Trace," 0.01 inch, 0.02 inch, 0.03 inch, and so on, in ascending series.

The frequency distribution of daily rainfalls is of the "extremely asymmetrical or J-shaped form"[1] of the statistician, the smallest amount being most frequent. In order to show that the J-shaped frequency distribution of daily rainfalls prevails throughout the widely differing rainfall regimes of the United States, I present in Table 1, and figures 1 to 5, inclusive, and figure 15, frequency distribution tables and curves for 15 United States Weather Bureau stations in the arid Southwest, the north Pacific coast, the upper Mississippi and Ohio Valleys, the Gulf States, the Lake Region and New England. These data are for the six months, April to September, inclusive, in the year 1914. Longer series would give smoother curves, as is indicated by taking the average shown graphically in figure 15. The six warmer months were chosen in order to secure, as far as possible, impersonal data, since the automatic raingages at regular Weather Bureau stations are then in operation, and while the recorded measurements are personal stick measurements, they are likely to adhere quite closely to the automatic records, especially for small amounts.

[1] Yule, G. Udny. Theory of statistics. London, 1912. p. 98.

TABLE 1.—*Rainfall frequency distribution—Number of times various daily rainfalls (April to September, 1914, inclusive) have been recorded by automatic raingages.*

Station.	Amounts.																											Rainy days.*
	Trace.	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.25–0.99	1.00+	
Winnemucca, Nev	15	3	3	2	1	....	2	4	....	1	1	1	1	....	....	1	1	1	....	....	....	....	....	....	....	6	1	29
Reno, Nev	16	4	2	....	....	2	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3	......	12
Phoenix, Ariz	28	2	3	1	1	1	....	1	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	......	11
Portland, Oreg	13	11	1	....	3	2	....	....	2	2	2	1	2	2	2	2	....	1	3	....	2	....	....	....	....	14	......	52
St. Paul, Minn	21	6	7	4	1	3	3	1	1	1	4	....	....	1	1	2	....	....	1	....	1	....	2	....	2	19	5	65
La Crosse, Wis	23	5	5	1	2	1	3	2	2	1	3	....	1	....	....	2	....	1	....	....	1	....	....	1	....	23	10	64
Madison, Wis	23	10	5	3	....	3	2	2	1	....	2	2	....	....	....	....	....	1	1	1	....	....	....	2	2	16	7	60
Milwaukee, Wis	34	6	6	2	3	3	3	....	3	1	....	2	1	1	....	1	3	4	....	1	....	....	3	1	....	18	5	67
Green Bay, Wis	15	10	5	2	3	1	2	....	2	3	1	1	....	1	....	....	1	....	....	....	1	1	1	1	1	24	8	68
Vicksburg, Miss	22	8	4	2	1	1	1	3	2	3	....	1	....	....	1	1	1	....	....	....	....	1	....	....	1	14	8	53
New Orleans, La	24	7	3	4	4	2	1	....	....	....	1	1	3	4	2	....	....	1	....	....	2	1	1	1	....	26	8	72
Mobile, Ala	16	5	4	4	1	1	1	....	1	....	....	2	....	2	1	1	....	2	2	....	3	2	....	1	1	21	9	64
Columbus, Ohio	22	6	3	2	1	3	3	1	1	1	2	....	....	....	....	1	2	2	1	1	2	1	....	....	1	16	1	51
Boston, Mass	27	1	6	3	1	3	4	2	1	....	1	1	....	3	....	....	....	1	....	....	....	1	....	....	1	17	5	51
Northfield, Vt	23	5	6	7	5	3	2	1	1	1	2	....	2	3	2	1	1	....	....	5	2	2	....	2	....	22	3	78
Total	322	89	62	37	27	29	28	17	17	14	20	12	10	17	9	12	9	14	8	8	14	9	7	9	9	240	70	797
Average	21.5	5.9	4.1	2.5	1.8	1.9	1.9	1.1	1.1	0.9	1.3	0.8	0.7	1.1	0.6	0.8	0.6	0.9	0.5	0.5	0.9	0.6	0.5	0.6	0.6	....	......	......

* Days having a fall of 0.01 inch or over.

TABLE 2.—*Abnormal frequency distribution produced by observational error—Number of times various daily rainfalls (April to September, 1914, inclusive) have been recorded by cooperative observers.*

Station.	Amounts.																											Rainy days.*
	Trace.	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.25–0.99	1.00+	
Arthur, Nev	10	....	....	....	....	....	....	....	....	....	5	....	....	....	....	....	....	....	....	....	5	....	....	....	....	14	1	25+1
Gila Bend, Ariz	3	....	....	1	....	....	1	....	....	....	....	2	....	....	....	....	1	....	....	....	....	....	....	....	....	1	......	6
Salem, Oreg	1	4	3	1	2	3	2	4	....	....	1	....	1	1	....	....	....	....	....	1	2	....	....	....	....	19	......	44
Whitehall, Wis	5	....	....	....	....	....	....	....	....	....	11	....	....	....	....	....	....	....	....	....	9	....	....	....	....	27	5	52
Grantsburg, Wis	18	....	....	....	....	....	....	....	....	....	....	....	2	....	....	1	....	....	....	....	....	....	....	....	....	18	11	32
Neillsville, Wis	1	....	....	....	1	....	....	....	1	....	....	1	....	....	....	....	....	....	....	....	....	....	1	....	....	20	9	33+1
Medford, Wis	......	....	....	3	....	2	....	....	1	....	5	1	....	....	....	5	1	1	....	....	2	....	....	....	....	29	6	56
Koepenick, Wis	......	....	....	....	....	....	....	....	....	....	8	....	....	....	....	....	....	....	....	....	9	....	....	....	....	14	9	40
Port Washington, Wis	......	1	....	3	....	3	....	....	1	....	2	....	1	....	1	2	....	....	1	....	2	....	1	1	1	19	6	45
Oconto, Wis	......	1	2	....	1	3	1	1	....	1	1	....	1	....	....	2	....	1	1	....	2	....	1	1	....	23	8	51
Woodville, Miss	8	....	1	5	2	7	2	3	....	....	1	1	....	....	....	1	....	1	....	....	....	....	....	1	....	25	8	58
Waynesboro, Miss	28	....	3	....	....	5	....	....	2	....	4	....	1	....	....	1	....	....	1	....	4	....	1	....	....	19	9	50
Hattiesburg, Miss	8	....	....	....	....	....	....	....	....	....	1	....		....	1	....	1	....	1	....	1	....	1	....	1	13	11	31
Frankfort, Ohio	8	....	....	....	1	6	....	....	....	....	1	....	....	....	....	2	....	1	....	....	1	....	....	....	....	17	4	33
Cornwall, Vt	12	2	2	....	....	9	....	....	1	....	8	1	....	....	....	1	1	....	....	....	7	2	1	....	....	22	3	60
Total	102	8	11	13	7	38	6	8	6	1	48	6	6	1	2	15	4	4	4	1	44	2	6	3	2	280	90	616
Average	6.8	0.5	0.7	0.9	0.5	2.5	0.4	0.5	0.4	0.1	3.2	0.4	0.4	0.1	0.1	1.0	0.3	0.3	0.3	0.1	2.9	0.1	0.4	0.2	0.1	....	......	......

* Days having a fall of 0.01 inch or more.

The advantages of the frequency-distribution table, or curve, of rainfall as a test for personal error are as follows:

(*a*) The smallest amounts being most frequent make it very sensitive to observational error of any systematic kind, since the smaller amounts are less likely to be considered important by the careless or neglectful observer.

(*b*) The data are easily available, and easily reduced for the purpose, the operation consisting merely of counting.

(*c*) It affords a means of comparing the work of different observers in different parts of the country, since the recording of rainfall is a universal duty of meteorological observers, and because the J-shaped curve prevails in widely different districts. The number of small rainfalls differs much less from one district to another, than does the total rainfall.

Examples of markedly abnormal frequency distribution of daily rainfalls are given in Table 2, and figures 6 to 14 inclusive. The majority of these are from Wisconsin because they had already come to my attention in studies of local climate and not because they are more common in that State than elsewhere. These data are for the same period as the data presented in Table 1 and figures 1 to 5, and are comparable therewith.

Three principal types of personal error are apparent from these examples, viz:

(1) Those due to the failure to record light rainfalls, see figures 6, 7, 8, 9, and 10.

(2) Those showing that rainfalls have been noted and not measured, but estimated as "Trace," see figures 11 and 12. The observer at Waynesboro has recorded a greater number of "Traces" than the regular station at New Orleans.

(3) Those showing that the rainfalls have not been accurately measured, but recorded to the nearest tenth or twentieth of an inch. Figures 13 and 14 (Arthur and Koepenick) show this practice to be consistently followed in the observations represented, while figures 10 and 12 (Cornwall and Waynesboro), show it to be followed in part only. This peculiarity is well known in connection with the *estimation* [2] of the tenths of degrees in observing thermometers graduated to full or half degrees, but the measuring stick used in rainfall measurements is full divided, so that this form of personal error can not be regarded as subconscious. The tendency to *estimate* to even amounts appears very strongly in measurements of snowfall (wherein the factor 1/10

[2] Walter, A. On errors of estimation in thermometric observations. Qly. jour., Roy. meteorol. soc., 1909, 35: 249-257.

is used to reduce to water equivalent) as is seen in the following record of rainfall frequency for Madison, Wis., for the month of January for the 20 years 1871–1890. (The tendency has since disappeared at this station.)

TABLE 3.—*Frequencies of various rainfalls at Madison, Wis., during 1871–1890, inclusive.*

Daily rainfall.	Frequency.	Daily rainfall.	Frequency.	Daily rainfall.	Frequency.
Inches.	*Days.*	*Inches.*	*Days.*	*Inches.*	*Days.*
Trace.	39	0.10	17	0.20	11
0.01	6	.11	1	0.21 to 0.24	2
.02	13	.12	3	.25	4
.03	11	.13	1	0.26 to 0.29	4
.04	3	.14	1	.30	6
.05	9	.15	7	0.31 to 0.39	6
.06	9	.16	2	.40	7
.07	5	.17	2	0.41 to 0.49	2
.08	5	.18	0	.50	6
.09	1	.19	3		

A comparison of the total or average frequency of different amounts at the 15 regular stations in Table 1 will show a slight tendency to favor the fifth and tenth divisions, at the expense of the adjacent divisions. Among untrained observers the tendency becomes in some cases a ruling passion, as figures 13 and 14 and the average for the 15 cooperative stations in figure 15 clearly show. The following stations afford examples of markedly abnormal preference for the fifth and tenth divisions, corresponding to rainfalls of $0.05(2n+1)$ and $0.10n$ inches, where n is some whole number, throughout the whole range of recorded daily rainfalls, during the period considered, April to September, inclusive, 1914. Compared with the average frequency of "Trace" at the 15 regular Weather Bureau stations, 29 per cent, the percentage of "Trace" is evidently in excess at some, and deficient at others of these cooperative stations.

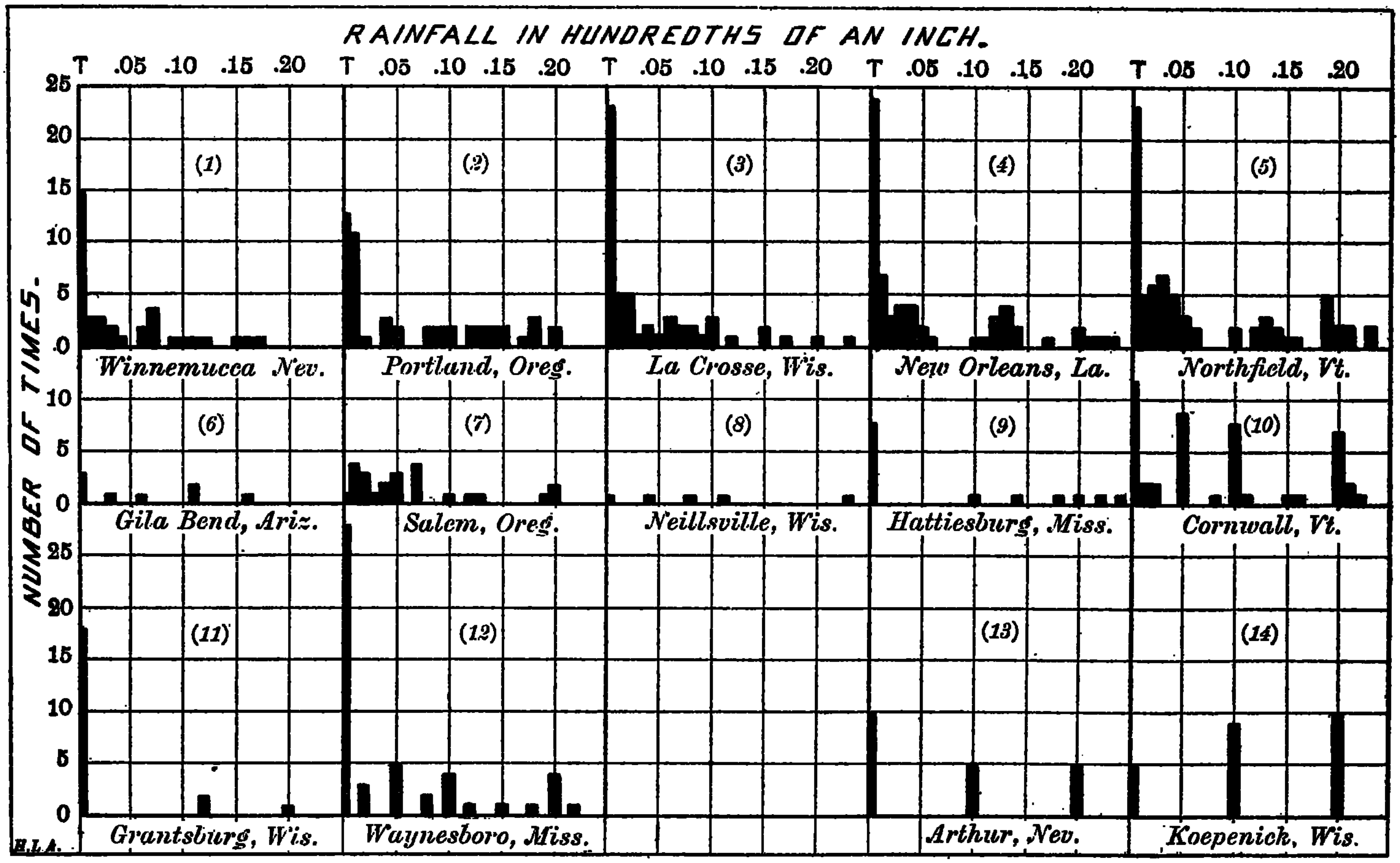

FIG. 1-14. Rainfall-frequency curves for 14 stations, April to September, 1914. *Abscissæ* show amount of the daily fall; *ordinates* indicate number of times each daily fall was recorded during the interval.

[The draftsman transposed some of these figures; imagine 13 under 6, 11 and 14 under 8, finally 12 under 9.]

TABLE 4.—*Examples of abnormal frequencies of the "5's" and "10's."*

Stations.	Relative frequency of the scale divisions:			
	5	0	1, 2, 3, 4, 6, 7, 8, and 9	Trace.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Koepenick, Wis.	0	100	0	0
Whitehall, Wis.	0	91	0	9
Arthur, Nev.	3	69	0	28
Cornwall, Vt.	30	32	21	17
Grantsburg, Wis.	30	30	4	36
Neillsville, Wis.	18	44	35	3
Waynesboro, Miss.	15	28	21	36
Frankfort, Ohio	41	15	24	20

Consideration of the probability of occurrence shows how unnatural these records are.

The influence upon the total rainfall for a month or a year, or upon the average rainfall, of these personal errors is probably not of any greater importance than the other errors affecting the measurement of precipitation. Their influence may, however, be felt strongly in other data relative to precipitation, perhaps most of all in the average number of "Rainy days." This effect is shown in Table 5, in which the regular Weather Bureau stations are set in black-face type.

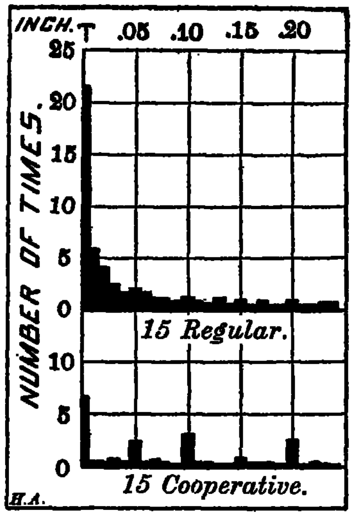

FIG. 15. Average frequency curves for daily rainfalls, April to September, 1914, as recorded at 15 regular Weather Bureau stations and at 15 cooperative stations. (See table below.)

Summary of daily rainfalls recorded in figure 15.

	Trace.	0.01 to 0.24	0.25 to 0.99	1.00 +
At 15 regular stations	322	487	240	70
At 15 cooperative stations	102	246	280	90
Coop./Regular.	32%	51%	117%	129%

TABLE 5.—*Average number of days with 0.01 inch or more of precipitation in Wisconsin.*

[From Summary of Climatological Data for Sections 58, 59, 60.]

Station.	Length of record.	Number of rainy days.	Station.	Length of record.	Number of rainy days.
	Years.	*Days.*		*Years.*	*Days.*
Ashland	16	78	Prentice	11	86
Barron	16	75	Stevens Point	17	78
Butternut	13	81	Valley Junction	18	89
Downing	15	73	Viroqua	19	100
Duluth	39	**131**	Wausau	14	102
Eau Claire	19	86	Amherst	16	81
Grantsburg	17	70	Appleton	10	108
Hayward	19	86	Beloit	17	77
Osceola	17	79	Brodhead	11	94
Red Wing	9	79	Chilton	15	101
Spooner	13	68	Crandon	11	70
Wabasha	14	88	Delavan	13	81
Weyerhauser	7	84	Florence	17	78
Whitehall	15	77	Fond du Lac	17	**93**
Dodgeville	10	78	**Green Bay**	23	**124**
Dubuque	36	**116**	Lake Mills	17	111
Grand Rapids	11	84	Madison *	31	111
Hancock	18	89	Manitowoc	17	98
Hatfield	12	69	**Milwaukee**	39	**128**
Hillsboro	19	76	New London	14	80
Koepenick	18	99	Oconto	18	96
La Crosse	37	**117**	Oshkosh	16	71
Lancaster	18	83	Pine River	15	94
Mauston	14	88	Port Washington	16	80
Meadow Valley	19	86	Racine	14	89
Medford	19	66	Shawano	13	88
Neillsville	21	56	Sheboygan	10	94
Portage	14	81	Watertown	18	100
Prairie du Chien	22	88	Waupaca	14	88

* 26 years cooperative, 5 years regular station.

The great differences between the records of stations manned by professional observers and those made by amateurs may be reduced to some extent by considering only the same period, but they are mainly due to differences in the fidelity to duty, as may be easily shown. This suggests the possibility of classifying observers with respect to fidelity to duty by arranging them in the order of the total number of rainy days reported by them.

The table, or curve, of frequency distribution of daily rainfall, however, gives a valuable insight into the observer's habits of work; its use can not well be omitted by working climatologists or the directors of climatological services without danger of loss of valuable time and effort in dealing with worthless or vitiated data.

REMARKS.

Prof. John F. Hayford, director of the College of Engineering, Evanston, Ill., presents by request the following comments on the above paper:

EVANSTON, ILL., *May 17, 1915.*

The use of the daily rainfall frequency distribution as a test for errors in the manner indicated in Mr. Miller's paper, seems to me to furnish interesting and suggestive indications of the habits of the observer and the character of the errors in the record turned in by him.

The value of these indications depends primarily upon the use which is made of them. Two general classes of use may be considered: (1) They may be used as a means of inspection of the observer and his work; and (2) they may be used as a guide in testing the accuracy of cooperative rainfall observations and as indicating how to reach safe conclusions from them.

If your observers would take suggestions kindly and seriously, if having found a cooperative observer's observations considerably in error it were possible to replace him by some one else, and if a considerable amount of inspection of a cooperative observer's work were possible, the indications obtained from the frequency-distribution tests advocated by Mr. Miller would be of considerable value as a part of inspection. * * *

As a guide in testing the accuracy of cooperative rainfall observations and as indicating how to reach safe conclusions from them, it seems to me that the frequency-distribution tests are likely to prove valuable if carefully considered and applied. In my opinion, the necessarily careful consideration involves traveling farther along Mr. Miller's line of thought than he has yet gone, judging by his paper. It may lead in some cases to added confidence in the records rather than the reverse The following paragraph is, possibly, a fair example of a reason for increased confidence based on frequency-distribution tests.

Consider the "Summary of daily rainfalls" under figure 15. This summary indicates that the cooperative observers missed 220 "Traces" (322−102) which may be estimated as 0.005 inch each, or a total of 1.1 inch; and 241 rainfalls between 0.01 and 0.24 inch (487−246), which may be estimated at 0.12 inch each, or a total of 28.9 inches. The total loss thus established *in these two groups* is, therefore, 1.1+28.9=30 inches. This is less than 10 per cent of the total shown in Table 2. This evidence indicates, therefore, that the total precipitation lost from the record in the form of smaller rainfalls which are unrecognized or erroneously recorded by the cooperative observers as a group, is possibly less than 10 per cent and almost certainly less than 20 per cent of the total amount. Are not other errors, in part unavoidable, probably larger than this? For example, is not the error in the total rainfall for a region produced by peculiarities in the geographical distribution of the stations and in the location with reference to the topography frequently much greater than 10 per cent? Will not any reduction in the number of cooperative stations tend strongly to increase the errors referred to in the preceding sentence?

The errors in the recorded total precipitation produced by the mere habit of concentrating the readings at 0.05, 0.10, 0.15, etc., are probably less than 5 per cent, and possibly less than 1 per cent—too small to be of importance. I reached this conclusion from a hasty study of Tables 1 and 2 and figure 15.

It seems to me that Mr. Miller's reasoning is conclusive in showing that the number of rainy days per year has one significance for regular stations and quite a different significance for cooperative stations.—*John F. Hayford.*

THE HOTTEST REGION IN THE UNITED STATES.

By G. H. WILLSON, District Forecaster.

(Dated: Weather Bureau, San Francisco, Cal., July 5, 1915.)

When the gold seekers and pioneers came to California in the early fifties many of them crossed the deserts in the southeastern portion of the State, and the intense heat experienced in that region during the summer months soon became well known and much feared. The sufferings of both man and beast while traveling over those dreary wastes have been the subject of many interesting papers, some of which were based upon facts while others were pure fiction. Undoubtedly many lives